Optical SETI with Air Cerenkov Telescopes

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ABSTRACT

We propose using large Air Cerenkov Telescopes (ACT's) to search for optical, pulsed signals from extra-terrestrial intelligence. Such dishes collect tens of photons from a nanosecond-scale pulse of isotropic equivalent power of tens of solar luminosities at a distance of 100 pc. The field of view for giant ACT's can be on the order of ten square degrees, and they will be able to monitor 10 to 10^2 stars simultaneously for nanosecond pulses of about 6th mag or brighter. Using the Earth's diameter as a baseline, orbital motion of the planet could be detected by timing the pulse arrival times.

Subject headings: communication, interstellar, SETI, instrumentation

1. Introduction

Optical searches for extra-terrestrial intelligence (ETI) were first proposed by Schwartz and Townes (1961) not long after the invention of the laser. They have been invigorated by the realization that a civilization with Earth 2000 technology and a sun similar to our own could, for a brief enough interval, outshine its sun in the optical in a sufficiently well collimated direction. For example, a 30 kilojoule pulse, lasting 1 nanosecond with a 10^{-13} ster beam, gives an isotropic equivalent power along the beam axis of 10 solar (bolometric) luminosities. Thirty gigawatt-years of such pulses would fill a fair fraction of the sky. A civilization that expended an average of 30 gigawatts (roughly 1/10 of the average U.S. electrical consumption) in such pulses for, say, a star-wars type defense system, might thus become inadvertently detectable. Far less energy would be required for us to be within such a beam if the signals were deliberately directed at other stars like our Sun. Thus, a civilization might choose to broadcast its existence with brief optical pulses. OSETI programs that use modest astronomical telescopes with angular resolution of order 1 arcsec are underway (Shvartsman *et al*. 1993, Beskin *et al*. 1997, Horowitz *et al*. 2001). Below, we suggest that optical dishes with poorer angular resolution may offer an alternative strategy for OSETI.

The question then arises as to what sort of pulse would be required to exclude the possibility of a natural source (which, one might argue, a self-proclaiming civilization would deliberately choose in order to avoid ambiguity). At the very least, they would be sure to make the pulses outshine their sun by a comfortable margin that would allow unambiguous detection. In fact, existing OSETI teams have proposed searching for megajoule pulses that could outshine our sun by a factor of 10^3 or more. However, the strong

constraints posed by ecological considerations and the desire to broadcast as much information as possible might cause them to opt for weaker pulses. At a distance of 100 pc, a solar luminosity, L_{solar}, produces a flux at Earth of about 10^{-6} optical photons per cm^2 per nanosecond. We assume, then, that an ETI would produce the minimum signal that would stand out comfortably above this flux.

In this paper we consider the possibility of monitoring many stars at once in an OSETI program using air Cerenkov telescopes (ACT's). These dishes, planned for ground based gamma ray astronomy, are to be outfitted with nanosecond imaging cameras. They offer the following advantages:
1) Greater sensitivity, because of their large size ($\sim$ 10 meter diameters)
2) Large field of view (up to $\sim$ 10 square degrees), which, combined with the first advantage, would allow monitoring of many stars at once for sufficiently strong pulses.
3) Since the dishes will be built for ground based gamma ray astronomy, OSETI programs could be implemented at some level by introducing appropriate data storage and processing.

A disadvantage, however, is that a significant amount of empty sky would be monitored, and this would require additional effort in noise rejection, as discussed below.

2. Materials and Methods

Giant optical dishes such as the planned air Cerenkov telescope (ACT) MAGIC (Major Atmospheric Gamma Imaging Cerenkov telescope, 236 m^2) (Barrio *et al.* 1998) and the recently constructed PETAL (Photon Energy Transformer and Astrophysical Laboratory, 400 m^2) dish (see figure) are, as far as we know, the largest optical reflecting dishes in the world. Arrays of ACT's, such as VERITAS (Very Energetic Radiation Imaging Telescope Array System) and HESS (High Energy Stereoscopic System), will have total areas of up to $\sim 10^3$ m^2, distributed over many (4 to 10 or so) dishes. They are quite inexpensive per unit collecting area in comparison to astronomical telescopes. The MAGIC surface, diamond-turned aluminum, will cost roughly US\$1K per square meter, and can provide angular resolution of about 1.5 arcminutes. The typical pixel size for the camera, however, will be on the order of 0.1 degree in diameter for the inner pixels and about 0.2 degree for the outer ones. The PETAL surface, backsilvered glass, has an angular resolution on the order of 0.2 degree, and costs $\sim$US\$100 per square meter. The surface is globally paraboloidal, so that nanosecond pulses are not smeared by significant spread in path lengths to the focus. The most expensive item in the latter case is the molds, and we believe that resurfacing the dish with polished sheet metal shaped on the existing molds could improve the angular resolution at a cost of tens of US dollars per square meter.

We now consider the required thresholds for signals. To record a small number of actual nanosecond pulses per year ($\sim 3 \times 10^{16}$ nanoseconds), we assume that false signals must be reduced to one part in 10^{17} as a standard of confidence. The diffuse night sky background under good conditions, about 22.5 mag star per square arc second, translates to about 1.3×10^{-7} photons/cm^2 nanosecond in the blue (B) band in a typical pixel size of 30 square arcminutes (somewhat greater than a solar luminosity at 100 pc, about 10th magnitude, which would give about 0.08 photons in the blue band for a standard solar spectrum). If this were the only background, assuming Poisson statistics, a 100 m^2 collecting area would register a clear signal (less than one false event per year) with 11 B band photons arriving in a nanosecond bin. This would correspond to about 140 L_{solar} at 100 pc. An area much lower than 100 m^2 would give insufficient statistics for the large detection confidence that the problem requires. A weaker signal would require a smaller pixel size to surmount the night sky background. However, the smaller pixel size would only help if the host star

of the extra-terrestrial civilization were fainter than 10th magnitude. Similarly, restricting the search to faint host stars would not help, given the diffuse background, if the pixel size is kept at about 30 square arcminutes. Altogether, it seems that typical parameters for large ACT's are well suited for OSETI out to 100 pc.

Using a value of 1.3 x 10^{-7} photons/cm^2 nanosecond in the blue band for the background photons rate per pixel, we have found that a clear signal from a nanosecond laser pulse with isotropic equivalent blue band luminosity of much less than 140 L_{solar} at 100 pc would require many hundreds of square meters of net collecting area (i.e. factoring in quantum efficiency). We estimate that the minimum isotropic equivalent luminosity that could be detected above noise with ACT's of three or four hundred m^2 would correspond in the B band to about 50 to 70 L_{solar} at 100 pc, or about a 6th magnitude star. We find that for 1000 m^2, at least 26 L_{solar} at 100 pc is required. We also find that the minimum detectable intensity is slightly less in the red (R) band; though the signal to noise is less in the red band, the higher photon count rate compensates for this. The (presumably) monochromatic spectrum of the laser pulse would work in favor of picking it out of the background, and the above estimates, if expressed in solar bolometric luminosities, would be about an order of magnitude lower, depending on the details of the detection scheme.

Air Cerenkov flashes produced by cosmic rays and gamma rays typically have durations of 3 to 5 nanoseconds and present a major noise problem. Although they typically produce an imageable track that covers many pixels, low energy hadronic cosmic rays (protons in the 10 to 100 GeV range) may produce individual pions that might produce quasi-pointlike clumps of optical photons. These clumps can contain on the order of 10 photons and lie within a single pixel. Though they are generally accompanied by many other photons in other pixels, it is possible that, at the energy at which pion production is marginal, single clumps would occasionally masquerade as pointlike optical flashes. The arrival rate of 30 GeV protons in the ACT field of view (some $10^{-3.5}$ of the sky with a collecting area of about 5 x 10^8 cm^2) is about 6 x 10^3/second. Even if one in ten such protons produces a pointlike optical flash that gets past image selection, this amounts to a probability of nearly 10^{-6} per nanosecond for a chance event. Such noise events can be selected out by stereoscopic selection by using three to four suitably spaced dishes in coincidence. Arrays of ACT's, such as VERITAS and HESS, seem suitable for this technique if appropriate trigger criteria and software are implemented.

Yet another noise source is cosmic rays passing through individual pixels. The modest angular resolution might mean that a point source triggers more than a photomultiplier, allowing for charged cosmic ray secondary particles going through individual photomultipliers to be eliminated. However, a better method might be multidish coincidence as discussed above.

The key point of this section is that area, rather than optical quality, is the relevant dish parameter that needs to be maximized. Poor angular resolution can be tolerated for OSETI because of the short pulse duration given that nanosecond time binning is used .

In the above, we have chosen a pixel size that is small enough that the diffuse night sky background is not much more of a problem than the host star of a solar luminosity at 100 pc, and this happens to be about 10^5 square arcseconds, the pixel size of next generation ACT cameras. The minimal signals we considered for confident detection at such a distance translates to tens of kilojoules for a nanosecond pulse of 10^{-13} ster. For brighter signals, such as the megajoule pulses considered by Horowitz and co-workers (2001), the minimal angular resolution is a significant fraction of a degree, and huge collecting surfaces could be made less expensively. The PETAL dish, serendipitously, is nearly ideal for such purposes.

Rather than monitoring individual stars, the dish can merely look off into space, while doing whatever

else it was designed to do. With a field of view of 12 square degrees, as per the current design of the MAGIC camera, and an assumed range of order 100 parsec, such a dish would cover about 10^2 stars.

Most of these stars would be thought incapable of supporting life. On the other hand, it is hard to know for sure what fractions to consider and to reject. Moreover, it is hard to know *a priori* what strength optical pulses are worth looking for. Stronger pulses allow deeper searches, and the search volume could be larger than the 10^3 pc^3 that we have envisioned here.

3. Detecting Orbital Motion

Two ACT observatories on different continents could verify that optical pulses came from a planet orbiting the star if they simultaneously detected repeated pulses over several months. Using the Earth as a baseline, and allowing for the limited number of ACT's worldwide and the need for simultaneous observing not too close to dawn or dusk, etc., one could obtain with ns resolution an angular resolution on the order of 10^{-7} radians. Even at a distance of 100 pc, then, the orbital motion of an ongoing signal could be detected if the orbital radius is 1 AU or more. In contrast to Doppler and timing techniques, this would not depend on the pulses being received regularly or on the accuracy of the clocks of the ETI.

A multi-continental simultaneous observing program would increase the collecting area, enhance the capability for coincidence-based noise rejection (especially if there is concern about local and regional sources of non-Poissonian noise), and would thus ease the requirements made on each individual ACT observatory. Thus, there is added motivation for such a transcontinental OSETI effort. The discussion in this section applies as well to OSETI with smaller area and better angular resolution.

4. Summary and Discussion

We have argued that giant parabolic dishes with modest angular resolution and large fields of view offer an enhanced, cost effective search capability for OSETI. Their larger collecting areas and fields of view ultimately allow them to monitor many stars at once even while doing gamma ray observations. If they are dedicated to OSETI, then, unlike smaller telescopes, they could target candidate host stars with more sensitivity or those at greater distances. If, as seems probable, the number of pixels roughly equals or exceeds the number of stars monitored at once, then an individual star thought to be associated with a positive signal (or in any case a short list of suspects) could be identified for further monitoring with classical astronomical angular resolution.

The price paid for monitoring 10 or more square degrees at once is an enormous cosmic ray background. However, the next generation of ACT arrays seems capable of handling this problem in principle with suitable online software. Moreover, an ET civilization intent on self-broadcasting with laser pulses might design their time profiles to stand out above this background.

5. Acknowledgments

We thank Profs. Sandra Faber, David Faiman, Sergey Biryukov, Noah Brosch, Jill Tarter, Phillip Morrison, Phyllis Morrison, and Sergey Karpov for fruitful discussions. This research was supported by

the Arnow Chair of Theoretical Astrophysics, ISF grant 208/98-2, the Russian Foundation of Fundamental Research (grant 01-02-17857) and the Russian Federal Program "Astronomy".

Figure caption: The PETAL optical reflecting dish in Sede Boqer.

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